Land Use and Climate Change

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By the

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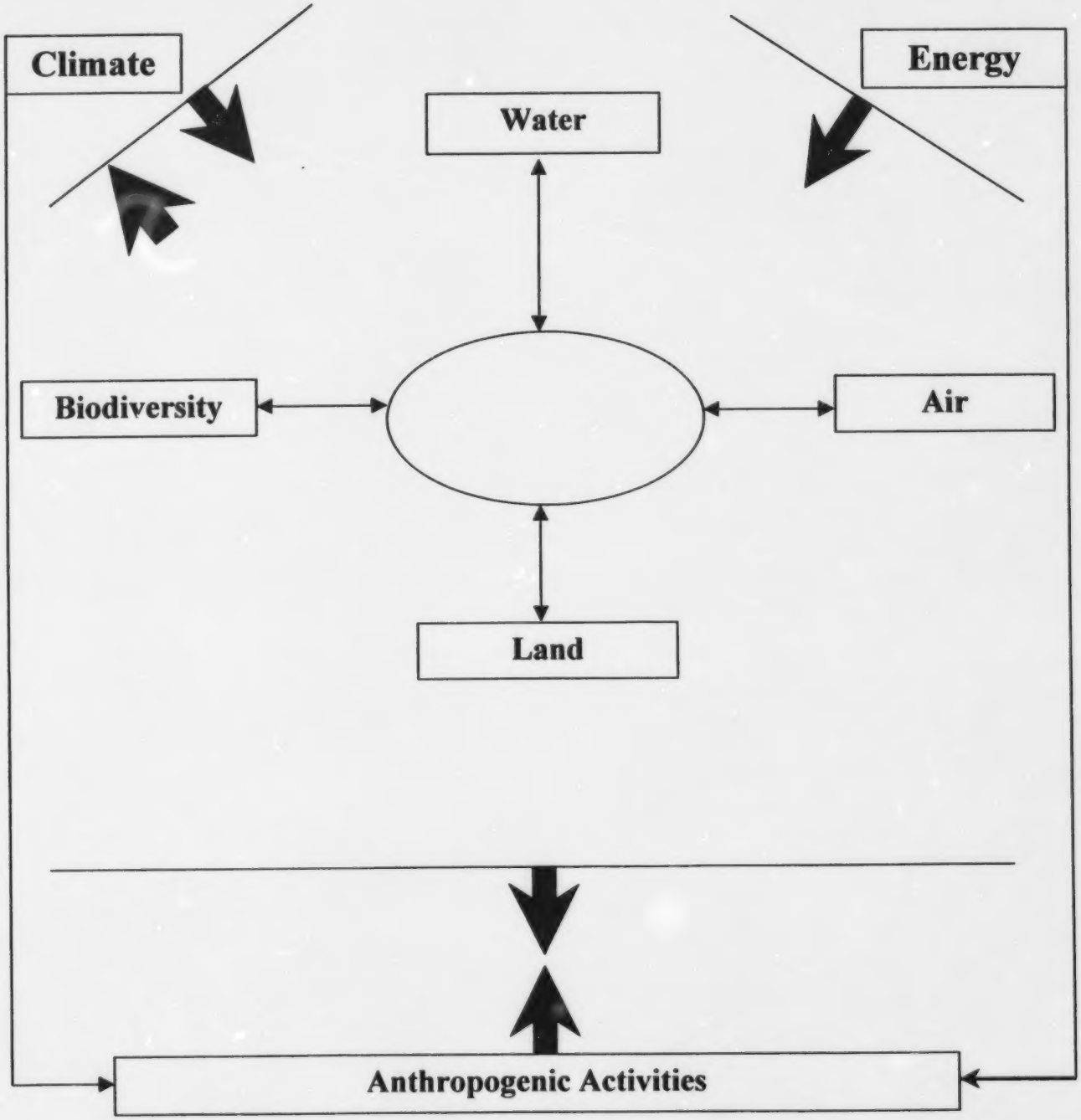
Introduction

Land use and climate change as related to the agricultural sector involves relationships characterized by multiple linkages (Figure 1, Inputs and Linkages Model for Land Use Types, IISD 1998). Changes in climatic conditions can cause quantitative fluctuations of other influences, which can in turn affect land use options and practices. For example, as atmospheric carbon levels increase, driving global warming, there may be a decrease in precipitation amounts on the prairie landscape, as suggested by many climatic change models. This would result in less available moisture for recharge of wetlands. The reduced viability of the wetlands would result in increased pressures to convert this 'marginal' land into productive agricultural land, rather than trying to maintain it in the face of less available moisture availability. The implications of this change in land use, is that there may be a change in the carbon cycle, possibly a release of carbon to the atmosphere, which in turn drives the global warming cycle and on. Lands that were once sequestering carbon may no longer do so, and may in fact become sources of other greenhouse gases such as methane. The dilemma becomes clear...climate change and land use change are intricately linked; they are inseparable, and as such cannot be considered exclusive of each other.

On a broad scale, land uses include agriculture, forestry and wetlands. On a more specific scale, as per Bruce et al. (1998), agricultural land uses include cultivated land, revegetated or set-aside land, pastureland, rangeland, and degraded land. Non-agricultural types of land use include wetlands, marshes, both permanent and temporary, and forests. The interface between various land uses is also important.

This document will review various land use types related to agriculture, including interfaces with various land uses, and how these uses may influence their roles as sinks or sources of greenhouse gases.

Figure 1: Inputs and Linkages Model for Land Use Types



Background

The major greenhouse gases related to agriculture and land use are carbon dioxide and methane. Carbon dioxide is released to the atmosphere as a result of disturbance of soils when land is converted or the land management technique is changed. Methane may be released by wetlands and is influenced by the hydrological state of the location. In addition, the release of nitrous oxide takes place during the burning of biomass, a practice related to land use changes from forestry to agriculture. Adger (1995) states that the land use causes of global warming are related in the main to land use change. Large reservoirs of carbon exist undisturbed in soil and biomass. The fluxes associated with normal growth and regeneration are small compared to those when land use is intensified or when use of the land is changed (Adger 1995). Richards (1990, as cited by Adger 1995), reports that the observed trend of accelerating land use change in recent centuries has primarily been driven by frontier expansion and population growth. More specifically, it is the agricultural revolution and the associated opening of frontier that can explain the conversion of land from natural to agricultural use and has led to the release of carbon to the atmosphere.

Land Uses and Related Greenhouse Gas Emissions Impacts

Bruce et al (1998) have identified a variety of land uses related to agriculture, they include:

- Cultivated Land
- Revegetated or Set-Aside Land
- Pastureland
- Rangelend
- Degraded Land

For each of these land uses the authors have also identified related management practices and the potential relative impact the implementation of these practices on carbon sequestration for each the practices. Table 1, Management Practices That Can Increase Soil Carbon (Partial List), summarizes the strategies identified by the authors and the relative impact on carbon sequestration of each approach.

Over the last few decades agricultural practices such as tillage have resulted in this form of land use being a net source of carbon dioxide. Tillage breaks up the soil, releasing carbon to the atmosphere, but also contributes to erosion, which results in a loss of organic matter and the long-term ability of the soil to sequester carbon. Bruce et al (1998) state that agricultural ecosystems are usually net sources of nitrous oxide, which is generated during transformation of nitrogen in soil, particularly from soils high in inorganic N. Additionally, methane is generated by ruminant livestock, and by waterlogged soils, notably rice paddies (Bruce et al. 1998). Changes in practices can lead to a change in the role of a type of land use from being a source of greenhouse gasses to become a sink. An excellent example comes in the form of switching from summer fallow practices to minimum or zero tillage practices. Bruce et al (1998) state that because the quality and productivity of a soil is closely linked to its organic matter content, any increase in soil carbon will have important benefits for the sustainability and productivity of the agroecosystem. In addition, many of the practices that favour carbon accumulation, like reduced tillage and the use of perennial forages also prevent erosion, preserving the productivity of soils. Finally, carbon-sequestering practices may enhance the profitability of farming systems by increasing yields or reducing production costs (Bruce et al. 1998). Bruce et al. (1998) also suggest that the adaptation of carbon sequestering practices may also have secondary effects beyond the boundaries of the agricultural ecosystems. They may have benefits to air and water quality through reduced erosion, positive or negative effects on water quality and potential impacts on rural economies through changes in cropping practices (Bruce et al. 1998). As has been suggested, the implications of the linkages reviewed between land uses and factors such as environmental influences, climate change and anthropogenic influences, imply that any carbon sequestration strategy cannot be judged solely on its impact within the agroecosystem itself.

Table 1: Management Practices That Can Increase Soil carbon (Partial List)

Management Practice	Feasibility*	Relative Carbon Gain (per unit area)*
Cultivated Land		
Adoption of reduced or no till	H	M (large area)
Use of Winter cover crops	M	L
Improved crop nutrition and yield enhancement	H	L
Elimination of summer fallow	M	M
Use of forages in rotation	M	M
Use of improved varieties	H	M
Use of organic amendments	M	M
Irrigation	L	H
Revegetated or Set-Aside Land		
Re-establishment of perennial grasses	L	H
Soil/water conservation measures (e.g. grassed waterways, shelterbelts)	H	H
Reversion to woodland	L	H
Pastureland		
Improved grazing regime	M	M
Fertilizer application	H	M
Use of improved species/varieties	M	M
Irrigation	L	M
Rangeland		
Improved grazing regime	L	L
Degraded land		
Reversion to native vegetation	M	H
Establishment of fast growing crops	M	H
Application of fertilizers	H	M
Application of organic amendments	M	H
Drainage/leaching of saline soils	L	L

*H = high
M = medium
L = low

What We Know

North American soils account for approximately 22 percent of the terrestrial carbon pool. Waltman (1997) estimates that the total SOC (soil organic content) pool to a depth of 1 meter is 267 Pg for North America, with 52 PG for the United States, (contiguous states), 13.5 Pg for Alaska, 11 Pg for Mexico, and 190 Pg for Canada. Total area of cropland in the United States is about 170 million hectares or approximately 19% of total land area (Kellogg 1994). Lal et al. (1998) estimate that the historic loss of SOC from U.S. cropland may be as much as 5Pg. The improved cropland area in Canada is 45 million

hectares (Food and Agriculture Organization (FAO) 1995), representing a SOC pool of about 6 Pg to a depth of 1-meter (excluding pastureland). Bruce et al. (1998) suggest that the historic loss of SOC from cropland in Canada may be about 1 Pg. Therefore, the absolute potential of carbon sequestration with improved management of cropland in the United States and Canada is about 5.5 Pg, if losses could be fully recovered (Bruce et al. 1998). The authors suggest that with appropriate measures, a significant portion of this amount may be realized over the next 20 to 30 years.

Much of the carbon loss from agricultural soils occurs during the first decades after cultivation. Haas et al. (1957) report that losses of soil organic matter (SOM) are nearly exponentially in the first 10 to 20 years of cultivation.(Sala et al. 1996). This rate of loss has decreased with time, because of depletion of the readily decomposable carbon pools and the gradual improvement in soil management practices (Bruce et al. 1998). Dumanski et al. (1995) used the CENTURY model to determine the effects of changing land management on soil carbon sequestration. The authors calculate that the replacement of fallowland may sequester carbon for about 15 years under fertilized continuous cereal and zero-tillage, and for 25 years under hay crops before reaching steady-state levels. By replacing 3.1 million hectares of summerfallow by more intensive agriculture Dumanski et al. (1995) calculate that an additional 20 megaton of carbon could be stored under continuous cereal or 92 megatons under hay. One concern expressed by Dumanski et al (1995) is that any change in management practices to reduce carbon dioxide emissions may lead to an increase in nitrous oxide (N_2O) emissions. With nitrous oxide being 200 times as effective as carbon dioxide in absorbing infrared radiation, this could negate some of the benefits of reducing carbon dioxide emissions Dumanski et al. 1995).

Within the realm of climate change and land use a substantial amount of modeling has taken place to begin to answer two main issues:

- What is the role of specific land use types, i.e. are they sinks or sources?, and
- Can we quantify the amount of greenhouse gases they are sequestering or emitting, and if so how?

Models have been used extensively by organizations such as PFRA, Agriculture Canada and Environment Canada in relation to global warming and climate change. Modeling specifically for greenhouse gas emissions has also taken place, with a number of reports coming from Forestry Canada, PFRA, and NATO. PFRA has reviewed the relation of shelterbelts and agroforestry practices to their effect on carbon dioxide emissions and the carbon reservoir. This publication quantified the carbon benefits of trees and shrubs over a fifty-year period on a variety of soils and land uses (Kort and Turnock 1997). Based on three major soil types in Saskatchewan, it concluded that shelterbelts and other agroforestry practices have the ability to reduce carbon emissions and increase the amount of sequestered atmospheric carbon in the agricultural ecosystem (Kort and Turnock 1997). The results of this research are summarized in Table 2, Net differences in carbon emissions and reservoirs at 50 years, resulting from the incorporation of agroforestry practices.

In another document, Bruce et al. (1998), included the examination of (a) the magnitude of the potential for carbon sequestration in the soil as a means of reducing carbon dioxide in the atmosphere, (b) the methods available for estimating carbon sequestration on a farm or regional scale, and (c) additional information needs. The conclusions were that there was considerable potential for agricultural soils and degraded lands of the United States and Canada to sequester carbon.

Table 2: Net differences in carbon emissions and reservoirs at 50 years, resulting from the incorporation of agroforestry practices.

Emissions (50 year cumulative total) (tonnes carbon)	**Soil Zone**		
	Black	**Dark brown**	**Brown**
Farming	-45.00	-35.00	-30.00
Establishing field shelterbelts	+3.83	+4.10	+3.28
Heating house	-30.00	-30.00	-30.00
Establishing poplar plantation	+2.66	-	-
Establishing yard shelterbelts	+0.59	+0.59	+0.59
Establishing wildlife planting	+0.34	+0.75	+0.75
Harvesting poplar plantation	+0.13	-	-
Total (tonnes carbon)*	**-67.45**	**-59.56**	**-55.38**

Carbon reservoirs at 50 years: (tonnes carbon)			
Field shelterbelts	+516.6	+377.0	+342.6
Yard shelterbelts	+119.0	+81.8	+48.5
Soil carbon increase due to shelterbelts	+610.5	+297.0	+127.6
Grain carbon increase	+39.0	+213.0	+144.0
Poplar plantation	+1120.0	-	-
Native aspen bush	+1173.0	-	-
Riparian area	+79.5	+120.4	+267.8
Wildlife planting	+40.7	+92.5	+90.6
Total (tonnes carbon)**	**+3698.3**	**+1181.7**	**+1021.1**
Total carbon saving (tonnes)***	**3765.8**	**1241.3**	**1076.5**

*Negative values represent reductions in carbon emissions resulting from the incorporation of agroforestry practices.

**Positive values represent increases in carbon reservoirs resulting from the incorporation of agroforestry practices.

***Total carbon reservoir 9resulting from Agroforestry) + Total emission reduction (resulting from agroforestry).

Source: Kort and Turnock 1997

Richards (1990) summarized various databases and models to generate land use trends from 1700 to 1800 (See Table 4). The single most important trend identified is the reduction in the world's forests and woodlands, which are now 81 percent of their 1700 total (Adger 1997). During the same period of time, cropped areas have expanded at almost the same magnitude. The table also provides evidence that the rate of change has increased dramatically this century, with the absolute changes in world cropland being greater in the period 1950-1980 than in the 250 years before then (Adger 1997). The tabular evidence shows that although tropical deforestation has received the greatest attention, in particular in relation to greenhouse gas implications, over the timeframe of a few centuries, temperate and boreal deforestation is by far the most significant in areal terms. Mathews (1983), as cited by Adger 1997) estimates that from the pre-industrial era to the present, temperate forests have lost close to 20 percent of their area.

The impact of present land use changes on greenhouse gas fluxes is summarized in Table 3. Although there are some important trade-offs between the gases with regard to natural wetlands, changes in land use have detrimental effects by causing net emissions of greenhouse gases.

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Table 3: Greenhouse gas flux impacts of current land use trends

Current land use trends	CO_2	CH_4	N_2O	H_2O	Albedo
Increasing deforestation	+	+ (with burning) 0 (with clear-cutting)	+	-	+
Increasing use of paddy rice	0	+	+/-	0	0
Increasing N-fertilizer consumption	0	0	+	0	0
Increasing desertification	+	0	-	-	+

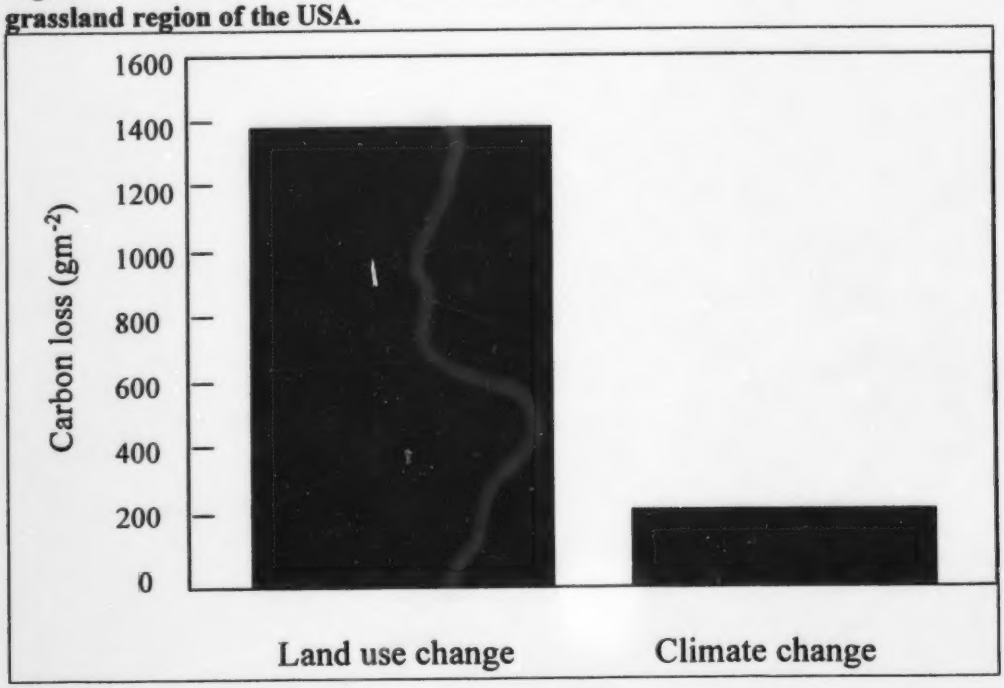
Source: Adapted from Bouwman (1990), as cited by Adger (1996).

Note: + = increased emission; - = decreased emission.

Sala et al. (1996) suggest that the greatest changes in the carbon budgets of temperate grasslands, for example, are as a result of management as related mainly to cultivation.. Transformation of grasslands to croplands can result in a net carbon flux to the atmosphere (Sala et al. 1996). The authors continue by stating that historically, all cropland management practices resulted in carbon losses and the depletion of soil organic matter (SOM). Tillage is known to increase decomposition by breaking soil aggregates and allowing previously protected material to be exposed to decomposers, and by placing surface residues so that they are in contact with the soil. In addition, inputs into SOM may be decreased as a result of shifting from perennial to annual plant species and the associated removal of a portion of the aboveground biomass during harvest(Sala et al. 1996). Through a combination of modeling and historical data analysis Burke et al. (1991, as cited by Sala et al. 1996) suggested that the emissions that occurred as a result of land use change in the central grasslands of North America were much larger than those which may occur as a result of the increase in temperature as predicted by the GISS global circulation model (Figure 2). Direct effects of carbon dioxide and changes in precipitation were not considered. Using the CENTURY ecosystem model, Burke et al. (1991) estimated that after 50 years of climate change, there will be a net loss of carbon ranging 50 to 350 gm^{-2}. In contrast, an historical analysis of field data indicated that as a result of cultivation since settlement of the plains, carbon losses are between 800 and

$200gm^{-2}$. The authors suggest that on a regional basis, past effects of cultivation have been much more important than the expected climate change as a control on carbon change. Their simulations resulted in emissions of 1.4 Tg Cyr-1 for the entire region, which is smaller than the 18 Tg Cyr-1 associated with the estimated large scale effects of historical cultivation. The concern over the losses of SOM and net carbon release into the atmosphere has resulted in new research on cultivation practices, and implementation of zero and low tillage approaches. Preliminary results indicate that these methods do have the potential to conserve and even increase soil carbon storage. Thus, these techniques can decrease or eliminate the negative effects of cultivation on carbon balances.

Figure 2: The effect of tillage and climate change on carbon losses from the central grassland region of the USA.



Source: Burke et al. (1991), as cited by Sala et al. 1996.

Sala et al. (1996) suggest that by converting cropland back to original ecosystem in the temperate grassland regions in the northern hemisphere will have important effects on regional carbon budgets. However, the authors suggest that the long-term significance of the conversation of cropland to grassland will depend upon regional, national, and worldwide surpluses of agricultural products.

Population growth is certainly the driving force behind increasing productive use of land and the intensity of land use. Over the same period of land use change (1700-1980), global human population increased more than sevenfold from0.6 billion to 4.43 billion.

Table 4: Land Use Changes 1700 – 1980

		Area (millions ha)					Percent changes from				
Region	Vegetation types	1700	1850	1920	1950	1980	1700 to 1850	1850 to 1920	1920 to 1950	1950 to 1980	1700 to 1980
North America	Forests and woodlands	1016	971	944	939	942	-4.4	-2.8	-0.5	0.3	7.3
	Grassland and pasture	915	914	811	789	790	-0.1	-11.3	-2.7	0.1	-13.7
	Croplands	3	50	179	206	203	1566.7	258.0	15.1	-1.5	666.7

Source: Adapted from Richards (1990), as cited by Adger (1997)

What are the gaps?

Bruce et al. (1998) identified several research needs and issues. Their findings included a general need to improve estimates of carbon sequestration in soils and develop a means of determining "verifiable change in stock". However, specific efforts were recommended on the following topics:

A refinement of existing models is required so that they may be applied at region scales. This includes the need to improve modeling of physiochemical and biological processes in the soil and, in the short term, improve existing models.

There is a need for better information on present and historic land uses as drivers of change in soil carbon.

A better understanding of potential effects of a changing climate on plant production.

In order to validate models and assess impacts of measures, more extensive site networks and data sets are required.

More extensive and reliable information on soil degradation by different processes, its severity, and extent, as estimated through critical soil property indicators in various ecoregions.

Improved assessments of the impact of practices intermediate between no-till and intensive tillage and of intermittent use of conservation tillage and related practices. Improved understanding of rates over time of carbon sequestration after introduction of revised management practices.

Development of innovative practices for deep placement of carbon and other measures.

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